SUBSTITUTE SPECIFICATION

METHOD FOR MANUFACTURING GALLIUM NITRIDE COMPOUND SEMICONDUCTOR AND LIGHT EMITTING ELEMENT

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a method for manufacturing a gallium nitride compound semiconductor, and in particular to a light emitting element with improved light emitting efficiency and a method of realizing such.

2. Description of the Related Art

In recent years, A1GaN and A1GaN quantum well superlattices (MQW) or the like have come to be known as materials for light emitting elements, particularly as materials for elements emitting light in the ultraviolet band. Typically, these materials are formed on a sapphire substrate, and dislocations are present due to lattice mismatch of an order of 108 ~ 109/cm2.

At a dislocation, an electron and a hole, which are the carriers, recombine without emitting light (non-luminous recombination). Because of this, as the dislocation density increases, the light emitting efficiency of a light emitting element in general decreases.

Fig. 4 schematically shows the band gap Eg of a material for a light emitting element. As show, when there is a spatial fluctuation in the band gap of the light emitting element material, light emission occurs only at the locations where the band gap is narrow (gap ("a" in the figure). Therefore, if the density of the light emitting points based on the spatial fluctuation of the band gap can be set to exceed the density of dislocations in the light

emitting element materials, it is possible to obtain a percentage of the luminous recombination occurring at the points where the band gap is narrow which is higher than the percentage of the non-luminous recombination of an electron and a hole at the dislocations (gap "b" in the figure), and, therefore, degradation in the light emitting efficiency can be inhibited.

SUMMARY OF THE INVENTION

One object of the present invention is to improve characteristics of a gallium nitride ~~compound~~ based semiconductor, such as, for example, light emitting efficiency, even when dislocations are present in the semiconductor.

In order to achieve this and other objects, there is provided, according to one aspect of the present invention, a method for manufacturing a gallium nitride ~~compound~~ based semiconductor, comprising the steps of (a) forming a first gallium nitride ~~compound~~ based semiconductor on a substrate; (b) forming of a composition material of the first gallium nitride ~~compound~~ based semiconductor a discrete area on the first gallium nitride ~~compound~~ based semiconductor; and (c) forming a second gallium nitride ~~compound~~ based semiconductor on the first gallium nitride ~~compound~~ based semiconductor onto which the composition material is formed. A spatial fluctuation is created in the band gap by producing a change in compositional ratio in the second gallium nitride ~~compound~~ based semiconductor by the composition material.

When the composition material is present, the solid phase composition of the composition material is increased in a gallium nitride ~~compound~~ based semiconductor when it is formed on the composition material. Because of this, the compositional ratio in the region where the composition material is present differs from that in the region where

the composition material is not present. Due to the difference in the compositional ratio, a spatial fluctuation is produced in the band gap. By forming the spatial fluctuation in the band gap, recombination of the carriers are facilitated at the region where the band gap is narrow, and, thus, the light emitting efficiency can be increased even when such dislocations are present. It is preferable that the spatial fluctuation of the band gap be formed at a density higher than the dislocation density. For example, if the dislocation density is $10^8 \sim 10^9/cm^2$, it is preferable that the spatial fluctuation be formed so that the average distance at the region where the band gap is narrow (light emitting point) is 1 um or less. The period of the spatial fluctuation of the band gap can be adjusted can be adjusted by adjusting the density of the discretely formed composition material.

According to another aspect of the present invention, there is provided a method for manufacturing a gallium nitride ~~compound~~ <u>based</u> semiconductor comprising the steps of (a) forming, on a substrate, a base layer created by forming a discrete layer for varying diffusion length of the composition materials of a gallium nitride ~~compound~~ <u>based</u> semiconductor; and (b) forming the gallium nitride ~~compound~~ <u>based</u> semiconductor on the base layer. A variation in the compositional ratio is produced in the gallium nitride ~~compound~~ <u>based</u> semiconductor through the variation in the diffusion lengths of the composition materials, in order to create a spatial fluctuation in the band gap.

When there is a layer which varies the diffusion lengths of the composition materials and a gallium nitride ~~compound~~ <u>based</u> semiconductor is formed on this layer, compositional change occurs between the composition materials of the gallium nitride ~~compound~~ <u>based</u> semiconductor as a result of the variations in the diffusion lengths. Because of the compositional change, a spatial fluctuation is produced in the band gap.

The period of the spatial fluctuation of the band gap can be adjusted by adjusting the density of the layer for changing the diffusion lengths of the composition materials.

According to still another aspect of the present invention, there is provided a method for manufacturing a gallium nitride ~~compound~~ based semiconductor comprising the steps of (a) forming, on a substrate, a base layer having a lattice mismatch; and (b) forming the gallium nitride ~~compound~~ based semiconductor on the base layer. A spatial fluctuation is created in the band gap of the gallium nitride ~~compound~~ based semiconductor by the lattice mismatch.

When there is a lattice mismatch, the thickness of the gallium nitride ~~compound~~ based semiconductor layer at the region where the lattice mismatch is present differs (namely, the thickness is narrower) from the thickness in the other regions. Due to this variation in the layer thickness, a spatial fluctuation of the band gap is produced. When the gallium nitride ~~compound~~ based semiconductor has a superlattice structure, the spatial fluctuation of the band gap becomes pronounced.

According to yet another aspect of the present invention, there is provided a light emitting element using a gallium nitride ~~compound~~ based semiconductor. The light emitting element comprises a substrate; a first gallium nitride ~~compound~~ based semiconductor layer formed on the substrate; a composition material of the first gallium nitride ~~compound~~ based semiconductor formed as a discrete area on the first gallium nitride ~~compound~~ based semiconductor layer; and a second gallium nitride ~~compound~~ based semiconductor layer having a compositional ratio variation and formed on the first gallium nitride ~~compound~~ based semiconductor layer on which the composition material is formed.

According to another aspect of the present invention, there is provided a light

emitting element comprising a substrate; a base layer formed on the substrate and created by forming a discrete layer for varying the diffusion lengths of the composition materials of the gallium nitride ~~compound~~ based semiconductor; and a gallium nitride ~~compound~~ based semiconductor layer having compositional ratio variation formed on the base layer.

According to another aspect of the present invention, a light emitting element comprises a substrate; a base layer formed on the substrate and having a lattice mismatch; and a gallium nitride ~~compound~~ based semiconductor layer formed on the base layer and having a spatial fluctuation in the band gap.

The present invention should become more apparent by referring to the following detailed description of the embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

Figs. 1A, and 1B are explanatory diagrams showing a method for manufacturing a gallium nitride ~~compound~~ based semiconductor according to the first embodiment of the present invention.

Figs. 2A and 2B are explanatory diagrams showing a method for manufacturing a gallium nitride ~~compound~~ based semiconductor according to a second embodiment of the present invention.

Figs. 3 is an explanatory diagram showing a method for manufacturing a gallium nitride ~~compound~~ based semiconductor according to a third embodiment of the present invention.

Fig. 4 is an explanatory diagram illustrating spatial fluctuation in a band gap.

DESCRIPTION OF PREFERRED EMBODIMENTS

Preferred embodiments of the present invention will now be described referring to the drawings.

Figs. 1A and 1B show a method for manufacturing a gallium nitride ~~compound~~ based semiconductor according to a first embodiment of the present invention. In the first embodiment, a light emitting element having a three-layer double hetero structure of n type $Al_yGa_{1-y}N$/undoped $Al_xGa_{1-x}N$/p type $Al_yGa_{1-y}N$ is manufactured.

First, as shown in Fig. 1A, an n type $Al_yGa_{1-y}N$ layer 12 is grown on a substrate 10 such as, for example, sapphire at a temperature of 1050 °C. Then, trimethyl gallium and nitrogen gas are supplied to the substrate for a few seconds at a temperature of 800 ~ 1050 °C, to thereby form on the n type $Al_yGa_{1-y}N$ layer 12 using MOCVD discrete gallium droplets 14 having diameter of approximately 10 ~ 500 nm.

Then, as shown in Fig. 1B, an undoped $Al_xGa_{1-x}N$ layer 16 is grown at a temperature of 1050 °C on the n type $Al_yGa_{1-y}N$ layer 12 onto which the Ga droplets (or micro-blocks of gallium) 14 are formed. Here, in the regions where Ga droplets are present, the solid phase composition of gallium within the undoped $Al_xGa_{1-x}N$ layer 16 becomes high, and thus, a spatial fluctuation is formed in the band gap of the undoped $Al_xGa_{1-x}N$ layer 16. In Fig. 1B, this phenomenon of composition variation within the undoped $Al_xGa_{1-x}N$ layer 16 due to the gallium droplets 14 is schematically shown by different hatchings. The undoped $Al_xGa_{1-x}N$ layer 16 can have, for example, a thickness of 0.05 um. Such compositional variation produces a spatial fluctuation in the band gap, that is, widening and narrowing of the band gap. After the undoped $Al_xGa_{1-x}N$ layer 16 in which the spatial fluctuation is produced in the bad gap is grown, a p type $Al_yGa_{1-y}N$ layer

18 is grown at a temperature of 1050 °C to produce a double hetero structure. These growth of semiconductor layers can be performed by mounting the substrate on susceptor of a reaction tube and sequentially introducing the material gas into the reaction tube while heating the substrate 10 with a heater.

The present inventors have confirmed that when a voltage is applied to a double hetero type light emitting element obtained as described above so that light is emitted, the illumination intensity is approximately 10 times the illumination intensity for a structure grown without forming the Ga droplets 14.

In the above example of the first embodiment, Ga is used as the material for the droplets 14, but the first embodiment is not limited to such as structure, and either A1 or Ga, which are both composition materials of the A1GaN, can be used. For example, droplets of A1 can be formed by flowing trimethyl aluminum onto n-A1GaN in place of the trimethyl gallium.

Figs. 2A and 2B show a method for manufacturing a gallium nitride ~~compound~~ based semiconductor according to a second embodiment. In the second embodiment, a light emitting element having a three-layer double hetero structure of A1GaN is manufactured, similar to Figs. 1A and 1B.

First, as shown in Fig. 2A, an n type $A1_yGa_{1-y}N$ layer 12 is grown on a substrate 10 at a temperature of 1050 °C, and a discrete SiN layer 15 is formed on the surface of the n type $A1_yGa_{1-y}N$ layer 12. In order to form a discrete SiN layer 15, the SiN layer can be formed first on the entire surface and then a portion of the SiN layer can be removed, or by adjusting the amount of flow of silane gas and ammonia gas, which are material gases for SiN. The region where the SiN layer 15 is formed becomes a mask section and the region

where the SiN layer 15 is not formed becomes a window section.

Next, as shown in Fig. 2B, a undoped A1GaN layer 16 is grown on the n type $A1_yGa_{1-y}N$ layer 12 onto which the SiN layer 15 is formed. Here, the growth begins at the window section where the SiN layer 15 is not formed and progresses onto the SiN layer 15. When the undoped A1GaN layer 16 is grown on the SiN layer 15, the compositions of A1 and Ga within the undoped $A1_xGa_{1-x}N$ layer 16 differ between the window and mask sections because the diffusion lengths of the Ga atom and A1 atom on SiN are different. More specifically, because A1 is absorbed by solids and does not migrate in S1N as much as does Ga, and, the A1 composition at the window section is relatively small. As the A1 composition decreases, the band gap becomes narrower (smaller), with a result that a spatial fluctuation is generated in the band gap of the undoped $A1_xGa_{1-x}N$ layer 16. After the undoped $A1_xGa_{1-x}N$ layer 16 in which a spatial fluctuation is formed in the band gap is grown, a p type $A1_yGa_{1-y}N$ layer 18 is grown, to obtain a double hetero structure.

With the second embodiment, as with the first embodiment, a spatial fluctuation in the band gap can easily be created with a density greater than or equal to the dislocation density, and, thus, the light emitting efficiency can be improved.

Fig. 3 shows a method for manufacturing a gallium nitride ~~compound~~ based semiconductor according to as third embodiment of the present invention. In the third embodiment, a light emitting element is manufactured having a A1GaN/GaN quantum well superlattice structure.

An A1GaN layer 20 is formed on a substrate (not shown) and then a GaN layer 22 is formed. These layers are formed in a similar manner in a repetition of n pitches (n can be set, for example, as 20) to obtain a superlattice structure. The thickness of each layer

can be set at 1 ~ 100 nm, for example, 5 nm. When forming the GaN layer 22 on the A1GaN layer 20, a discrete layer (lattice mismatch layer) 21 of a material having a relatively high lattice mismatch, more specifically, A1N, InN, AlInGaN, Si, MgN, or the like is formed, and the GaN layer 22 is formed on the A1GaN layer 20 onto which this layer 21 is formed. Each of the layers including the layer 21 can be formed by MOCVD, as with the above two embodiments. When there is a substance having a large lattice mismatch at the interface of a superlattice, minute unevenness is generated on the surface. Because the thickness of the GaN layer 22 in the portion of the unevenness differs from that of the other portions, the thickness of the layer becomes non-uniform. Due to this non-uniformity, the quantum level based on the quantum effect spatially varies and the band gap is spatially fluctuated. By forming the layer 21 with a density sufficient to set the density of the spatial fluctuation of the band gap to greater than or equal to the dislocation density, the light emitting efficiency can be improved.

The present inventors have confirmed that when a voltage is applied to a light emitting element having a superlattice structure as shown in Fig. 3 (using A1N as the layer 21), a light emission intensity of 10 times that produced when the layer 21 is not formed can be achieved.

While illustrative embodiments of the present invention have been described, the present invention is not limited to these embodiments, and various modifications can be made within the scope of the invention. For example, in Figs. 2A and 2B, a material other than SiN, for example, SiO_2, can be used as the layer for varying the diffusion lengths for the composition materials of A1GaN.

Also, although Fig. 3 shows a lattice mismatch layer 21 formed on the A1GaN layer

20, it is also possible to form the lattice mismatch layer 21 on the GaN layer 22 and form a spatial fluctuation in the band gap of the A1GaN layer 20.

Furthermore, although Fig. 3 shows an example employing an A1GaN/GaN MQW structure, the MQW can be constructed from other materials. For example, the MQW structure may be preferably formed from A1GaN/A1N/GaN. In such a case, the lattice mismatch layer 21 can be formed at the interface between A1GaN and A1N and the interface between A1N and GaN.